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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 06001

SUBJECT: Laser Propagation through the Atmosphere, Airplane versus Balloon Testing - Case 720

DATE: June 2, 1969

FROM: W. Gale
S. L. Penn

ABSTRACT

[redacted]

Two NASA Center concepts for testing vertical propagation characteristics of the atmosphere at laser frequencies were presented at a meeting attended by the authors. One, by Marshall Space Flight Center, centers on an airplane instrument platform; the other, by Goddard Space Flight Center, utilizes balloons. The airplane offers heavier airborne payloads and the possibility of further experiments at minimum recurring costs. The balloons offer more stable paths, complete profile measurements, and longer observation times, but no airborne laser. The time schedules and costs are similar. The concepts are directed toward gaining an understanding of the basic processes of atmospheric propagation and furthering the prospects for successful laser communications between Earth and space.

The previous experience of Goddard Space Flight Center in studying atmospheric effects is also reviewed.

(NASA-CR-106774) LASER PROPAGATION THROUGH THE ATMOSPHERE, AIRPLANE VERSUS BALLOON TESTING (Bellcomm, Inc.) 11 p

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MEMORANDUM FOR FILE

INTRODUCTION

The possible application of lasers to high data rate communications is being widely studied. For space communication, direct laser links between space vehicles and earth stations are among the principal modes under consideration. Tests of varying complexity have already been performed between earth based lasers and earth orbiting satellites (e.g., GEOS II, near earth, and Surveyor, on the moon). A space borne CO_2 laser experiment is planned for ATS-F (1972). It will consist of a communications evaluation by Goddard Space Flight Center and meteorology studies by Bell Telephone Laboratories.(1) Contractual efforts, reported on earlier(2-4), to define an Optical Technology Experiments System which would provide for the joint development of both astronomical telescope and optical communication technologies are being followed up by separate contracts in each of those areas. The communication area includes a major role for atmospheric propagation tests.

This memorandum reports on two proposed propagation experiments presented for review by MSFC/Chrysler and GSFC at a meeting at NASA Headquarters on March 26, 1969. The MSFC/ Chrysler team proposed a system using an airplane borne laser and ground based detector while GSFC proposed a balloon borne detector for a ground based laser. These programs could be completed by the summer of 1971, prior to the ATS-F mission.

THE AIRPLANE EXPERIMENT

In the airplane concept, U2's, provided by the Air Force, would carry a 500-800 lb laser/detector system at altitudes up to 70,000 feet* over ground sites located at MSFC and, if desired, GSFC or elsewhere. Parameters to be measured are: pulse distortion, amplitude and phase,

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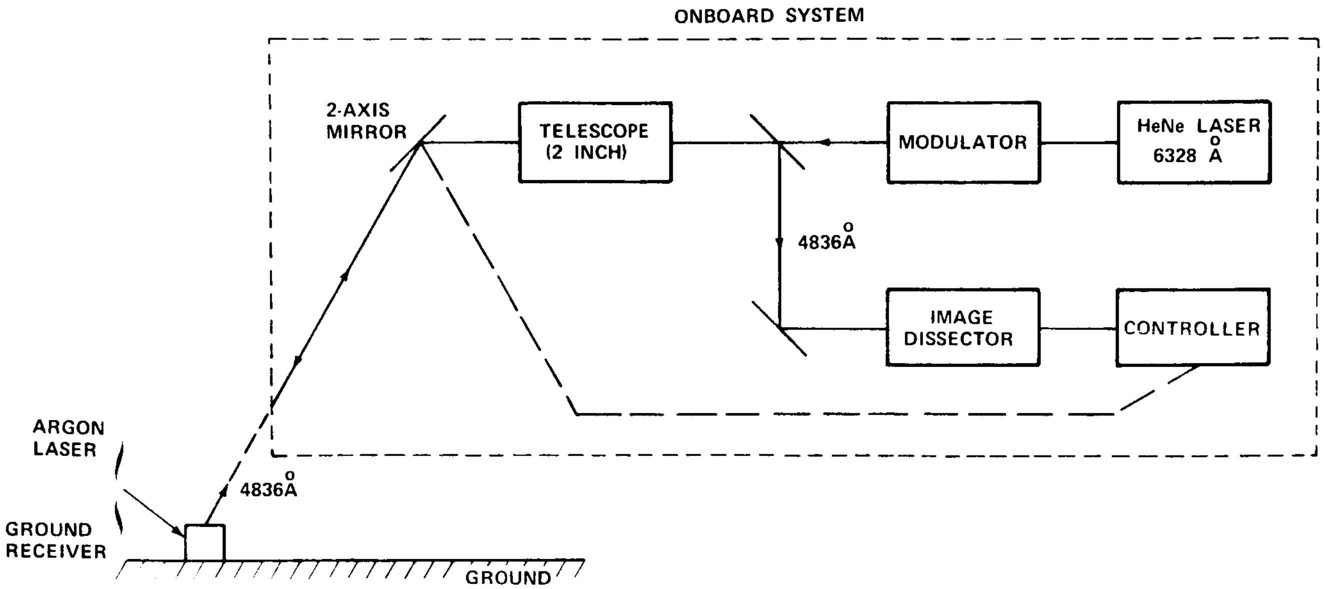
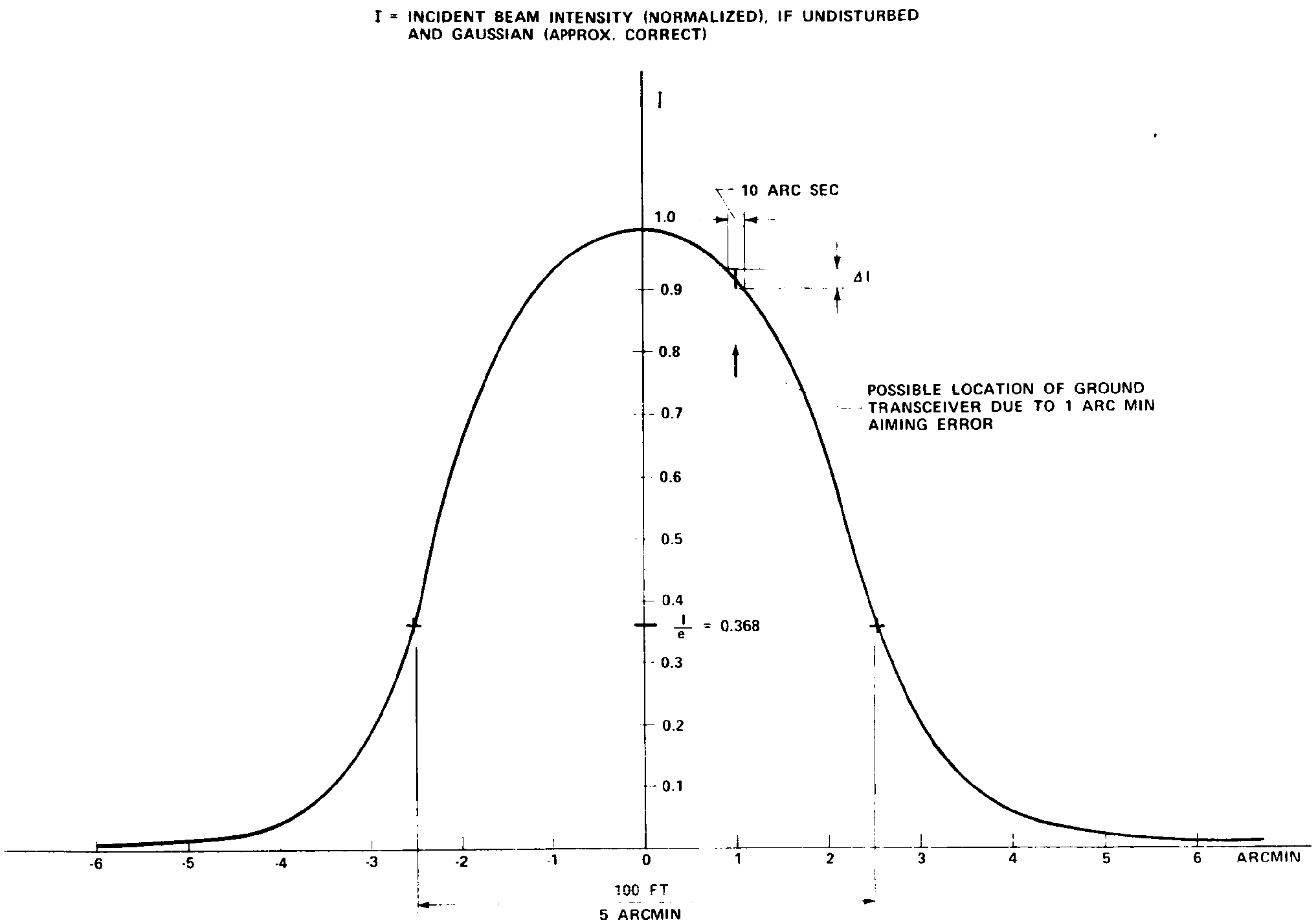
* There is good reason to believe that almost all stellar scintillation is caused by turbulence below this altitude.

coherence diameter, and far field pattern. Experimental observation time would total about 30 minutes per flight; 6 flights are suggested. Follow-up experiments beyond the present planned program would include multi-wavelength propagation and tests of precision tracking. The experiment system is depicted in the following sketch and its operation is described below.



In operation the planes are tracked by ground based argon laser beacons, guided by FPS-16 radars at nearby air force bases. The onboard telescope forms an image of the argon ground laser on the image dissector. The point image is then centered on the dissector by servo control of the two-axis mirror. This enables the plane's HeNe laser to point to within one arc min of the ground station. From an altitude of 70,000 feet, this would cause an off center displacement of about 20 feet. The beam from the HeNe laser/ telescope combination has a 5 arc min (1.5 milliradian) spread, causing the spot on the ground to be less than 100 feet in diameter when the plane is at 70,000 feet. (Diffraction limited laser performance with a non-distorting atmosphere would make this about one foot, too small for the pointing capability of the system).

The principal problem with this system is that fluctuations in beam intensity due to the 10 arc sec short term stability of the pointing system may mask the atmospheric effects being investigated. The following sketch illustrates the extent of the possible fluctuation.



It is preferable, of course, to have the beam center pointed close enough to the ground receiver so that fluctuations in pointing keep us on the relatively flat peak of the intensity curve. This would be attainable with a more complicated system than proposed, but would increase the program cost from ~$300K to ~$360K.

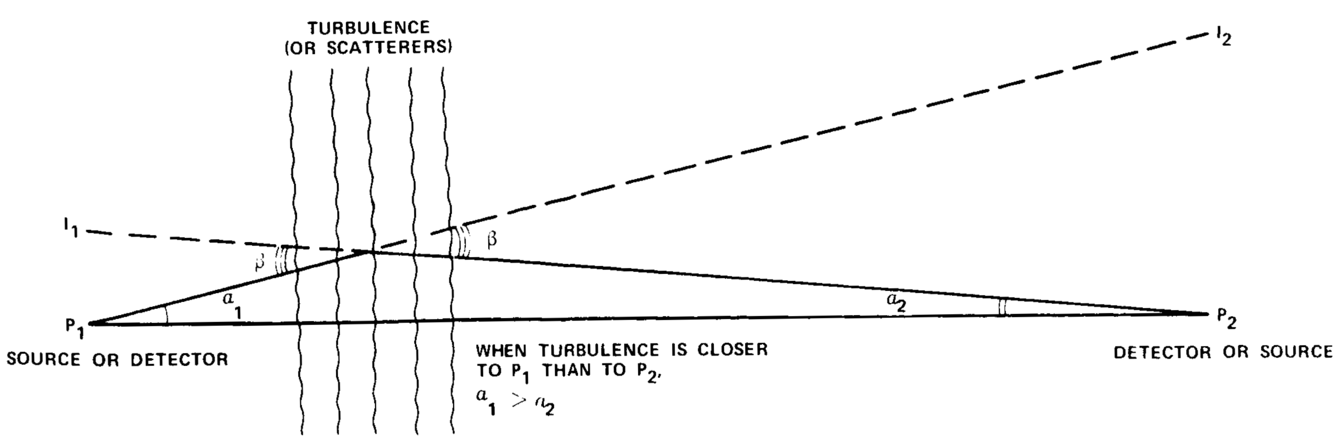
Acquisition of the airplane (and, hence, the ground site) was thought to be a possible problem. It should not be troublesome, however, if the radar and ground laser beacon are adequately synchronized. The maximum slewing rate, due to an overhead pass, is only 0.4 degrees/sec. To further facilitate acquisition, the ground laser beacon can be beefed up to provide a wider beam, greater output power, or both. This would be simpler than a similar upgrading of the airborne laser, because of weight and volume restrictions.

Another possible problem is that the plane's motion causes the line of sight to continually change, crossing different atmospheric turbulence profiles and, hence, providing a modulation that would exist even if there were no fluctuation in each individual path. This modulation might be compensated for (in the signal analysis) if it has a clear, determinable characteristic frequency, as might be the case if the turbulence in adjacent paths is similar and the speed of the plane is constant. Boundary layer turbulence at the plane is not seen as a problem since air flow over the belly section housing the experiment equipment is expected to be laminar (as determined from wind tunnel tests).

GSFC BACKGROUND IN ATMOSPHERIC STUDIES

Goddard Space Flight Center presented a description of the fundamental studies of atmospheric effects which it has conducted with the GEOS II satellite. A summary of the studies along with the authors' comments follows.

Mounted on the GEOS II satellite is a detector (no laser) for measuring the characteristics of the incident beam from a ground based argon laser, and a microwave transmitter for relaying back the results. Their findings from this testing are that "upgoing and downgoing scintillation is the same if you have spherical sources and point detectors." This was not elaborated on and its relevance is not clear to the writers. Scintillation has many aspects (pulsation, dancing, etc.), and in practice we would be dealing with extended detectors (large telescopes) and extended incident plane waves (star light and, in the future, light from remote lasers). The following sketch shows how intervening turbulence closer to one point than another causes disparate angular scintillation.



In the above diagram I_1 and I_2 represent the respective source image displacements observed by the detectors. It can be seen that, even though the refraction angles β are identical, as required by reciprocity of the beam paths, the angular displacements α_1 and α_2 are unequal.

A surprise finding of GSFC from their GEOS II slant path tests is that atmospheric transmission of the argon beam was only 30% instead of the 75% expected. This result is not understood quantitatively; but, since the tests were performed in the Washington, D. C. area, scattering by atmospheric pollutants appears to be the likely culprit.* GSFC has also conducted stellar image monitor tests, which confirmed that image sizes (angular fluctuation) get larger as angles from the zenith get larger.

In ground propagation tests GSFC confirmed a few things which might be expected from elementary refraction considerations; e.g., (1) the scintillation of CO_2 lasers (10.6μ) was down by a factor of 30 from that of visible lasers, hence CO_2 is a better candidate for heterodyne communications, which depend on the coherence properties of the beam; (2) spatial correlation across a laser beam goes down as the separation between points in the beam equidistant from the source increases, and gets worse as turbulence worsens; and (3) there's negligible difference in the scintillation performance of argon (4836Å) and HeNe (6238Å) lasers, in contrast to the considerable difference between these and CO_2 at 10.6μ.

The significance of these tests, of course, is not so much that they confirm the expected qualitative effects, but that they provide a quantitative test of the basic theory. The tests have also provided GSFC with proven instruments and techniques for studying scintillation. Hopefully the data can be effectively applied in assessing the prospects for space communications.

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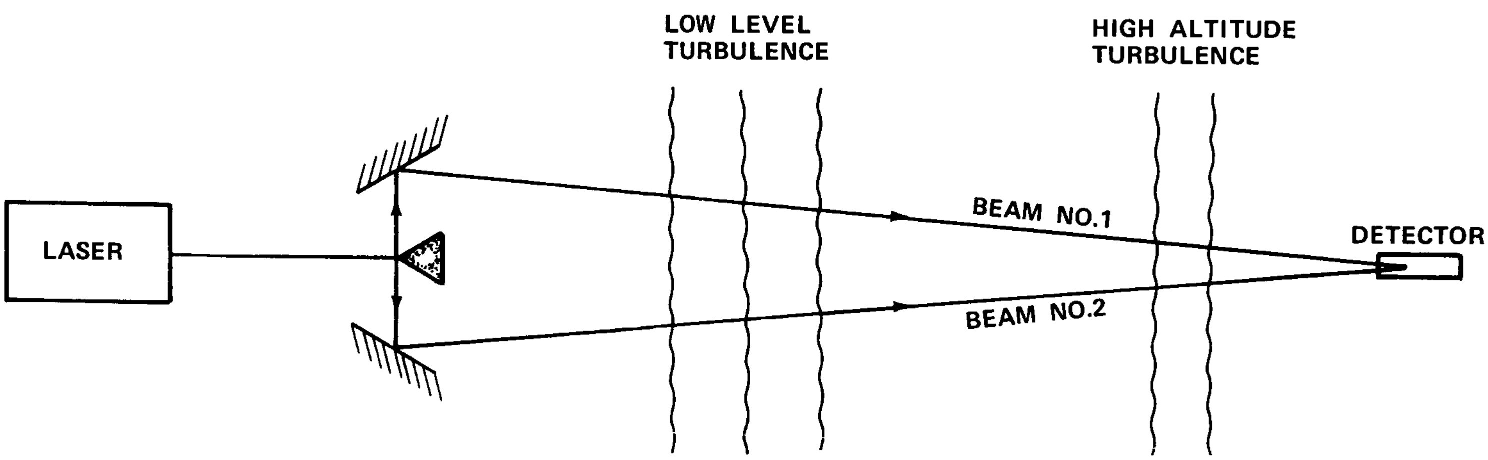
* As with the refraction due to turbulence, scattering causes a disparity between upgoing and downgoing beam displacements. The scattering is into small forward angles and the beam spreads farther in going up than in going down, since the scattering agents are closer to the ground.

THE BALLOON EXPERIMENT

The GSFC balloon tests are planned in the same vein as the satellite tests. The balloon borne detector (no laser) and telemetry package would weigh about 100 pounds. Following tethered balloon tests of the first few thousand feet, 4 balloons would be launched in a clear air region (Texas) to an altitude of 80,000 feet. A retroreflector would also be carried for tracking purposes. The ground system would consist of a single laser with its beam split and directed to equidistant mirrors of variable separation. The split beams are chopped in a manner suitable for analysis and then directed to the balloon along equidistant paths, requiring the baseline to be perpendicular to the line of sight. The following sketch illustrates this.



Correlation of the beam parameters would be checked as a function of mirror separation for two laser wavelengths: HeNe (6238Å), and CO_2 (10.6μ). To get an altitude profile of the turbulence, these tests as well as meteorological measurements would also be made as the balloon ascends.

CONCLUSIONS

Something of interest can probably be learned from both proposed atmospheric propagation tests. The balloon offers more stable paths, complete profile measurements, and longer observation times, but no airborne laser. The plane offers higher airborne payloads and possible further experiments at minimum recurring costs, but more problems with separating wanted from unwanted effects. Both programs have comparable time schedules (pre-ATS-F). The plane program for ≤$300K does not appear expensive. Cost figures for the balloon program were stated to be the same order of magnitude. The principal question in the writers' minds is whether the information gathered will be clearly applicable to deep space laser communications. The likelihood of this would be enhanced if tests similar to those planned here could be run concurrently with the ATS-F tests and a clear correlation between their results were found to exist. Meanwhile the proposed tests would be most useful in their own right as part of a methodical program aimed at a fundamental understanding of the relevant processes.

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Attachment
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